Concerns regarding the clock model used in 60802 time synchronization simulations

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IEC/IEEE 60802 Joint Project Call

Jordon Woods, Analog Devices

Background

- In the current simulations, local clock phase and frequency variation is assumed to be sinusoidal.
  - Frequency drift is assumed to be 3 ppm/s
  - Frequency Stability is assumed to be +/- 50 ppm
- This results in a sinusoid with the following characteristics

$$y(t) = A\sin(2\pi f_0 t)$$
$$\dot{y}(t) = 2\pi f_0 A\cos(2\pi f_0 t)$$

where

$y(t) =$ instantaneous frequency offset in ppm

$A =$ frequency offset amplitude in ppm

Setting A to 50 ppm and the maximum frequency drift rate $(2\pi f_0 A)$ to 3 ppm/s produces

$$2\pi f_0(50 \text{ ppm}) = 3 \text{ ppm/s}$$
$$f_0 = \frac{3}{100\pi} \text{ Hz } = 9.549\times 10^{-3} \text{ Hz} = 9.549 \text{ mHz}$$

- In this model, the sinusoid goes from -50ppm to +50 ppm and back to -50 ppm in less than 2 minutes.

Background

- This behavior is inconsistent with this contributor’s experience in real systems
- As such, I’ve been reviewing datasheets for xtal oscillators for the following parameters:
  - Frequency Stability: +/- 50 ppm is common. There are better and there are worse oscillators; however:
    - The Frequency Tolerance of a crystal is defined as the allowable deviation from the specified Frequency when measured at 25°C or room temperature. The Frequency Stability is defined as the allowable deviation considering temperature and other factors.
    - Frequency Stability includes initial tolerance, temperature, supply voltage & load change, and pressure.
    - Frequency Tolerance is typically on the order of +/- 10 to 15 ppm.
  - Frequency Drift: I can find no specifications for drift over time except for aging. Aging numbers run from 1 to 5 ppm/year.

Note: all specifications presented herein are based upon this contributor’s review of oscillator datasheets. This contributor does not claim this review is complete or comprehensive.

Problem Statement

- It is this contributor's opinion that the concept of frequency drift as a function of time is erroneous. Frequency stability should be modeled with the following assumptions
  - Frequency stability in an oscillator is dependent on several factors including aging, load, operating voltage, pressure and temperature.
  - The long-term stability effects of aging, load, voltage and pressure will be relatively constant over the period it takes to propagate a sync message over 64 hops (less than 1 second).
  - Long-term stability effects are accounted for by rate compensation.
  - The main dependency for frequency stability is temperature.

Temperature Effects

- The effects of temperature on a tuning fork crystal are given by the following equation:

$$f = f0 \times [1 - TC \times (T-T0)^2]$$

Where:

TC = thermal coefficient

f = frequency of the crystal

f0 = frequency at room temperature

T = ambient temperature

T0 = turnover point (room temperature)

Note: For a 25Mhz crystal oscillator TC = [0.030 … 0.050] ppm/°C^2.

Temperature Effects

- Assume the following:

  TC = 0.050 ppm/°C2

  f0 = 25 MHz

  T0 = 25 C

- At 85 C, f = 24995500 Hz; difference from f0: 4500 Hz or 180 ppm
- At -40 C, f = 24994718.75 Hz; difference from f0: 19531.25 Hz or 211 ppm

Conclusions

- Frequency error of the local clock should not be modeled as a function of time
  - No such specifications in oscillator data sheet.
  - Not representative of oscillator behavior.
- Frequency error should be dependent upon temperature with representative values for T, T0, f0 and TC.
- A representative thermal profile should be selected to form the basis for modeling frequency error.

Proposal

- Develop a frequency stability model for the local clock that depends on temperature
  - Calculate f based upon the enclosed formula or a suitable alternative.
    - Randomly assign f0 based upon frequency tolerance rather than frequency stability.
    - Choose representative values for T0 (25 C), and TC (0.050 ppm/°C2)
    - Select a representative thermal profile/cycle
    - -40 to +85 C; 25 C/min w/ 5-minute soak yields a period of 20 minutes

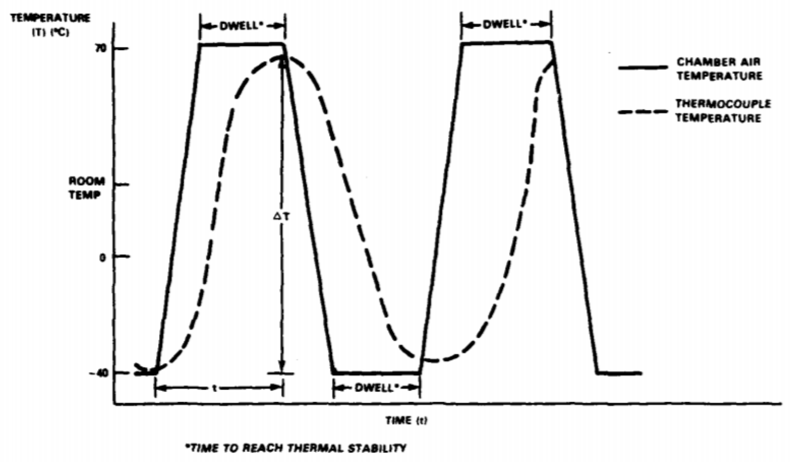

Figure 3. Typical PWA Thermal Cycling Profile

Thank you